Industrial applications’ simulation technologies in virtual environments
Part II: Virtual Manufacturing and Virtual Assembly

Bilalis Nikolaos
Associate Professor
Department of Production and Engineering and Management
Technical University of Crete
Chania, Crete, 73100, GREECE
bilalis@dpm.tuc.gr

Petousis Markos
PHD Candidate
Department of Production and Engineering and Management
Technical University of Crete
Chania, Crete, 73100, GREECE
petousis@dpm.tuc.gr

Antoniadis Aristomenis
Professor
Department of Natural Resources and Environment
Technological Educational Institute of Crete
Chania, Crete, 73133, GREECE
antoniadis@chania.teicrete.gr

Abstract: Virtual Reality technology when combined with the existing computer based simulation tools can accommodate the determination of functional and technical characteristics for products or production systems. Recently, software tools and methodologies have been developed for creating simulation environments, employing Virtual Reality technology. The characteristics of the simulation environments’ depend on the parameters that are studied and the objective of each system.

This study reviews different techniques that have been adapted for the study of product and processes parameters. A definition has been formed for each different technique, some of the most significant systems contemporary developed have been indicatively reported and the potentials of Virtual Reality technology as a simulation tool in industrial environments have been clarified.

Keywords: Virtual Manufacturing, Virtual Assembly, Virtual Prototyping, Virtual Reality, Virtual Environment, Industrial Simulation
1. INTRODUCTION

Product performance and production simulation constitute an essential part on every product design process. Nowadays, with the impressive development in computational systems, simulation employs Virtual Reality technology and is capable of providing:

- Real worlds’ visualization.
- Interaction between the user and the developed virtual environment.
- Study of specific product characteristics in almost realistic conditions.

Engineers can obtain information about the product or the process, that is not either feasible to be determined with traditional design methods or traditional design methods require significant higher cost and time.

Virtual Reality technology has also led to the development of new tools and techniques, for studying production processes focused on the study of specific production process parameters, like machining operations, assembly paths, etc. and supplement the conventional simulation systems. Nowadays a tendency is observed for simulation systems integration aiming at the development of integrated design systems. The applications that have been developed so far can be distinguished in the following three categories, according to the subject and the technology that is required:

- Virtual Manufacturing applications, focused on production processes, like machining operations.
- Virtual Assembly applications, which may be considered as part of Virtual Manufacturing applications. The distinction is due to the characteristics and the technology that Virtual Assembly applications require, which is different from the typical Virtual Manufacturing applications.
- Virtual Prototyping applications, focused on the study of the product, through digital mock ups development.

Below, a definition for Virtual Manufacturing and Virtual Assembly technologies is provided, based on the applications that have been developed. In addition, typical examples of Virtual Manufacturing and Virtual Assembly systems, which have been developed in research level or are been exploited in real industrial environments, are reported.

2. VIRTUAL MANUFACTURING

Virtual Manufacturing has prevailed to be applied mainly for production processes design, for which essential information is not feasible to be determined with any conventional method and has been focused mainly in machining and robotics systems operations, which are the most critical parameters for product production. It is a matured technology and has been used by several companies in various sectors and for different production processes. BMW [5] reports that computational tools are being used in fields where the use of the technology has been proved beneficial.
for the company in the past. Company estimates that it could determine simple process characteristics required in the design phase with less complicated methods. The need for using Virtual Manufacturing systems for every distinct production process design should therefore be evaluated. Contemporary products are very complicated and complicated methods and required for their production. The use of Virtual Manufacturing system could constitute an essential parameter for reducing cost and time for new product development. Production processes design aims at the determination of production parameters, like:
- production processes sequence,
- characteristics of every process that is required for the product production,
- production feasibility, with the designed process,
- raw material flow,
- final product shape.

Early Virtual Manufacturing systems provided production processes design capabilities, but did not provide visualization tools for the designed processes. Contemporary Virtual Manufacturing systems provide production visualization capabilities, through 3d graphics virtual production environment creation. Certain systems provide additional interaction capabilities between the user and the virtual environment employed for production visualization. The level of interaction is determined by the following parameters:
- Functionalities that are simulated in the virtual environment.
- Production characteristics that could be determined by the system.
- User and system interaction capabilities.

The simulation level is determined by the requirements of each application. In several applications the use of immersive peripherals (head mounted display, data glove, etc.) is not essential in the virtual environment that is developed (desktop applications). In systems, where production processes parameters require human intervention, the use of immersive peripherals is indispensable. Such systems could be used, apart from processes design also for personnel training in the processes required for new products production.

Fig. 1. Boeing application using Robcad software [6]
Fig. 2. Ford application using Visfactory software [7]
Fig. 3. University of Bath virtual environment [9]
Several companies, Boeing [6] (fig. 1), Chrysler [6], Mercedes [6], Renault [6], Nissan [6], Ford [7] (fig. 2) and BMW [7], employ commercial Virtual Manufacturing software, in which they verify and analyze production processes in new products development phase. In addition they have integrated CAD systems with production processes verification software, like spot welding, car body dyeing and individual parts assembly, which provide Concurrent Engineering methods implementation capabilities. The results from the use of such systems are product development cycle and cost reduction, improved product quality and reduced time to market.

2.1. Virtual Manufacturing applications
Virtual Manufacturing systems are indicatively presented. The systems described below include graphic environment, which constitutes an essential characteristic in contemporary systems, since it contributes in improving users and designers comprehension of the planned processes during the design phase.
GM [8] intends to develop a simulation system for an entire plant that would provide visualization of operating work cells (robot, raw material distribution, etc) and aims at reducing new product development time by at least six months. Bath University [9] has developed a simulation system for several types of machining operations (3 axis CNC, robot arm for dyeing, etc.) (Fig. 3) that provides virtual machines manipulation in a realistic way and could be employed for design, modeling and implementation of production plans in the virtual environment, aiming at errors detection in the executed operations. The final process could be transposed in CNC machine for the production of the part that has been designed with the use of the system.

Iowa University [10] has developed Virtual Reality applications (Fig. 4), for raw material distribution processes visualization, aiming at the determination of information that is required in decision-making, concerning the introduction of new processes and technologies. Another application comprises 5-axis machining

![Fig. 4. Iowa University virtual production line](image)

![Fig. 5. Iowa University milling simulation](image)

![Fig. 6. Yao, Li, Lee, Cheung and Yuan simulation system](image)
operations simulation (Fig. 5) aiming at parts final surface quality improvement, through the correction of the cutting tool path. The University system utilizes Virtual Reality peripherals, for user immersion and interaction with the virtual environment.

The University of Patras, [11] has developed a virtual machining operations environment for operations design and training. The system enables machining operations design, virtual machine-tools manipulation in a realistic way, production processes visualization, NC programs elaboration, verification and implementation. The system operates in an immersive environment with the use of suitable peripherals.

Yao, Li, Lee, Cheung and Yuan [12] have developed a machining operations virtual simulation environment (Fig. 6) that provides capabilities for dimension measurement, in order to determine the processed part precision and to measure final surface quality parameters. The system utilizes head mounted display and data glove. The integration with Virtual Reality peripherals provides the capability to utilize the system for training, apart from processes design.

3. VIRTUAL ASSEMBLY

Assembly processes compose a particularly critical parameter in a production process as:

- Assembly cost could reach 70% of the total production cost.
- Compatibility is required between the parts that will be assembled. Compatibility is a common cause of design problems and errors.
- Assembly processes usually require human intervention, in order to be accomplished.
- Assembly quality considerably influences the quality of the entire product.

A Virtual Assembly system is employed for assembly processes design and training and aims at determining parameters, such as:

- Assembly and disassembly sequence for Mechanisms
- Assembly path determination for every individual mechanism part.
- Time and cost for the accomplishment of the process.
- Assembly process feasibility and fitting of the mechanism’s individual parts.

Virtual Assembly systems could be employed as new product design tools and contain:

- 3D graphics virtual environment, in which product parts and work cell, with all the jigs and fixtures required for the executed process study, are being visualized.
- Virtual environment objects behavior simulation tools.
- Tools and peripherals for the interaction between the user and the virtual environment.
The main differentiation parameter on almost every Virtual Assembly system with the rest of Virtual Manufacturing systems is the need for human intervention study in the executed process, through human characteristics simulation. For human intervention simulation in the assembly process, two categories of systems have been developed:

- Systems, where the human factor is being studied through virtual mannequins, which move and execute processes in the virtual environment. Most of these systems do not include peripherals for the interaction of the user with the virtual environment. The process is being simulated in the computer display and the required process data are being acquired from the tools provided by the system.
- Systems, where the human factor is being studied through the interaction between the user and the virtual environment with the use of suitable Virtual Reality peripherals (head mounted display, data glove, etc.). In these systems user executes the assembly process in a realistic way and the quantitative and qualitative data arise according to user manipulations.

3.1. Virtual Assembly applications

One of the first remarkable systems for assembly processes implementation in Virtual Reality environment is VADE [13], [14] (Fig. 7). The system provides realistic interaction between the user, the environment and the virtual objects, collision detection and assembly tools operation simulation, capability for determining assembly paths though the realistic implementation of the process from the user. Moreover technical process parameters are determined, like the time required for completing every individual operation.

BMW [15] has developed a similar to VADE application, for new products assembly plans determination. The application has been integrated with the CAD and the PDM system of the company. This process is being accomplished 24 months before the introduction of the product in the market and includes studies for all the automobile’s parts. Since the study of the complete virtual automobile model is not feasible, the individual parts of each model (interior, engine, etc.) are studied separately. Assembly processes are being visualized through a wide screen (6m x 2.4m) and data acquired from the utilization of the system are being evaluated from the users (Fig. 8).

The same company has developed in research level an immersive virtual environment [16] for critical automobile parts (door, rear tail light) assembly and maintenance processes verification. This system provides voice activation capabilities for certain operations. The evaluation of the system (Fig. 9) showed that voice activation in combination with data glove was a more effective data input method concerning the use of keyboard. Many users considered that data glove handlings were not very precise. Moreover several users evaluated the vibration in the user fingers, when a collision with virtual objects occurs, as a non-realistic feedback method. Head mounted display was mainly considered as heavy and
inconvenient. Finally a general observation concerns user movement difficulties, due to Virtual Reality peripherals cables.

Fraunhofer Institute has developed another application with use of anthropoids for Industrial Engineering [17]. A virtual mannequin has been developed (Fig. 10), named VirtualANTHROPOS and it is used in determining processes ergonomics. A wireless telephone assembly application has been developed, which could moreover be used as a tool for personnel training, since it provides, in the design phase, processes visualization capabilities and enables their virtual implementation in a realistic way, though Virtual Reality peripherals utilization.

Another ergonomics application has been developed by the University of Patras [18] in manual assembly processes for shipyard applications and provides user immersion capabilities in the virtual environment with the use of Virtual Reality peripherals for the implementation of assembly processes in a realistic way. NIOSH ergonomics model has been integrated in the system for determining the allowed
weight the user can lift for the implementation of a process. With the use of GARG ergonomics model the energy the user consumes for the implementation of each process is determined, according to user characteristics (gender, weight, etc.).

4. CONCLUSIONS

Evaluating the applications described above, the use of virtual environments for simulating industrial applications shows adequate maturity, none the less not all the existing problems and restrictions have been confronted. It should be noted though that the integration of graphics technology with simulation models composes a powerful tool for the designers. Nevertheless applications development remains a time-consuming and difficult process. In the near future it is expected that all product data be digitally formed, which will constitute the beginning for all the product development software integration and the creation of a virtual factory, where the entire production process will be simulated. Virtual Manufacturing and Virtual Assembly technologies aim at reducing production cost and time and at improving the final product, by providing to the designers information about the product production methods that greatly contribute in improving design comprehension, locating technical problems and satisfying to a higher degree the predefined specifications. At the same time they compose a significant user introduction and training tool in the future applications.

References

[2] Intel Corporation
[3] Nvidia Corporation